Nitrogen Mineralization from Field-Applied Beef Cattle Feedlot Manure or Compost

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ABSTRACT

To apply manure or compost to fulfill N requirements of a crop, the amount of N mineralized in actual field conditions needs to be determined. Nitrogen mineralization from composted and noncomposted beef cattle feedlot manure applied to no-till and conventional tillage systems was determined under field conditions for 3 yr. Manure, composted manure, and inorganic fertilizer were applied to provide for N needs of corn. A no-treatment check was also included. An in situ resin method was used to determine N mineralization from a soil receiving manure, compost, and no treatment during the growing season (June–October). Of the organic N applied the previous autumn, ≈11% was mineralized from composted manure and 21% from noncomposted manure during the succeeding growing season. Lower N availability from compost reflects the loss of easily convertible N compounds during composting and the presence of stable N compounds. Nitrogen mineralization was similar in the no-till and conventional tillage systems even though manure and compost were surface-applied in the no-till. Nitrogen mineralization was significantly, but not closely (R^2 = 0.21), related to thermal unit (cumulative mean daily temperature >0°C). Mineralization rate constants indicated that availability of residual manure and compost N was less than expected. The in situ mineralization approach seems to be a good method of measuring N mineralization during the growing season or during periods when the soil is not frozen or excessively dry. Nitrogen mineralization needs to be considered when manure and compost are used for an environmentally acceptable crop production system.

BEEF CATTLE (*Bos taurus*) feeding is concentrated in the central and southern Great Plains. At any one time, at least 10 million head of beef cattle are receiving feed in the USA (USDA, 1997), and they excrete approximately 529 900 Mg N, 157 000 Mg P, and 482 000 Mg K annually (Eghball and Power, 1994). Beef cattle feedlot manure also contains ≈15% C that improves soil physical and chemical properties. Carbon in manure is likely to have far greater value than manure nutrients if applied to a low organic matter or eroded soil.

Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor or fly breeding potential. The other advantages of composting include killing pathogens and weed seed and improving handling characteristics of manure by reducing its volume and weight (Rynk et al., 1992). Composting also has some disadvantages, which include nutrient and C loss during composting; the cost of land, equipment, and labor required for composting; and the odor associated with composting. Eghball et al. (1997) found 20 to 40% loss of total N and 46 to 62% loss of total C during composting of beef cattle feedlot manure, as well as significant losses of K and Na (>6.5% of total K and Na) in runoff from composting windrows during rainfall.

Factors that may affect mineral composition of animal manure are animal size and species, housing and rearing management, animals' ration, manure storage, and climate. Nitrogen contents of beef cattle manure were 31, 42, 27, and 19 g N kg^{-1} (dry weight basis) when collected from scraping under slotted floors, in pits or tanks, bedded units, and feedlots, respectively (Overcash et al., 1983). Nitrogen is often lost by NH_3 volatilization from stored manure. Gilbertson et al. (1971) recovered only 42 to 55% of the estimated excreted N in feedlot manure indicating that the rest was lost.

Most studies determining N mineralization from applied manure have been conducted in the laboratory (Castellanos and Pratt, 1981; Chae and Tabatabai, 1986; Bonde and Lindberg, 1988; Cabrera et al., 1993). Other studies have determined availability of nutrients by plant nutrient uptake (Motavalli et al., 1989; Eghball and Power, 1999a, 1999b) or by grain yield (Bitzer and Sims, 1988).

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Table 1. Characteristics of beef cattle feedlot manure and composted feedlot manure applied for 4 yr at Mead, NE. Nutrients, C, and ash contents are on dry weight basis.

Year and source	Total C	Total N	Total P	Ash	Water content	NO_3–N	NH_4–N	EC†	pH†
	g kg^{-1}					mg kg^{-1}		d S m^{-1}	
1992									
Manure	78.4	7.9	3.20	844	195	30	1263	4.6	7.3
Compost	95.0	11.0	6.60	808	332	117	169	7.4	7.7
1993									
Manure	133.1	10.2	4.00	715	539	17	480	5.2	8.8
Compost	87.4	7.7	2.15	796	403	38	33	2.2	8.3
1994									
Manure	237.0	15.6	3.27	591	200	11	365	5.4	8.2
Compost	73.5	7.6	4.07	849	340	383	55	6.1	7.2
1995									
Manure	172.8	13.0	3.16	677	251	130	898	3.8	7.3
Compost	68.2	7.8	3.05	798	150	294	97	6.0	7.7

† Electrical conductivity (EC) and pH were determined on 2:1 water to dry manure or compost ratio.

The in situ resin core method has been used to measure N mineralization and nitrification in forest ecosystems (DiStefano and Gholz, 1986; Binkley et al., 1992). The method has also been used in a dryland agroecosystem to determine N mineralization (Kolberg et al., 1997). Generation of in situ mineralization data can be time consuming and costly, but is valuable for developing a practical mineralization index for waste products.

The amount of manure to be applied to a particular soil depends on the composition of manure, the crop grown, and environmental conditions. Nitrogen pools in composted manure differ from those in noncomposted manure. In composted manure, most of the easily mineralizable N has already been converted to inorganic forms and may be lost, and the remaining organic N is in more stable N pools. The amount of manure or compost N mineralized under field conditions needs to be determined in order to apply these resources to provide adequate N for the crop without adverse environmental effects. The amount of N mineralized from organic sources during the growing season provides a major portion of the plant N needs. The objective of this study was to determine N mineralization during the growing season from composted and noncomposted beef cattle feedlot manure applied to conventional and no-till corn (*Zea mays* L.) systems under field conditions.

MATERIALS AND METHODS

An experiment was initiated in 1992 on a Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudolls) under rainfed conditions at the University of Nebraska Agricultural Research Center near Mead, NE. The soil at this site had a Bray and Kurtz no. 1 P test of 79 mg kg^{-1}, pH of 6.3 (1:1 soil/water ratio), total N of 1.6 g kg^{-1}, and total C of 18.7 g kg^{-1} in the top 15 cm of soil. Total N and C were determined based on the method described by Schepers et al. (1989). The experiment was a split-plot in a randomized complete block design with four replications. Tillage systems of conventional and no-till were main plots. The conventional system included autumn and spring disking and cultivation for weed control. The conventional plots were cultivated for weed control in addition to using herbicide {Bullet [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide + 6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine]} in the corn rows. Weed control in the no-till plots was achieved by herbicide application. Subplots consisted of four treatments of composted and noncomposted beef cattle feedlot manure, commercial fertilizer, and untreated check. Manure, compost, and fertilizer were applied to provide for corn N requirements (151 kg available N ha^{-1} for an expected 9.4 Mg ha^{-1} grain yield; Gilbertson et al., 1979). No chemical fertilizer was applied to plots receiving manure or compost. Characteristics and rates of applied manure and compost are given in Tables 1 and 2, respectively. In the fertilized plots, $(NH_4)_2HPO_4$ (18–20–0, N–P–K) was applied at a rate of 25.8 P kg ha^{-1} and additional NH_4NO_3 (34–0–0, N–P–K) was applied to provide a total of 151 N kg ha^{-1}. Fertilizer was applied each spring before planting. Manure and compost were applied late autumn (November–December) and incorporated within 1 or 2 d into the top 10 cm of soil by disking in the conventional tillage plots in 1992, 1993, 1994, and 1995. In the no-till plots, manure and compost were broadcast on the soil surface in the autumn without incorporation or subsequent tillage. Treatments were applied on the same plots every year. Additional information regarding grain yield and N uptake in this study is provided in Eghball and Power (1999a).

Manure and compost rates applied in autumn 1992 were based on the assumption that 40, 20, 10, and 5% of the applied N would be plant available in the first, second, third, and fourth years after application, respectively (Gilbertson et al., 1979). This assumption was found to be an overestimation of N availability from compost since N availability from compost was approximately 20%, based on plant N uptake in 1993. Nitrogen from fertilizer was assumed to be 100% plant available during the year of application. Therefore, assumed N availability from compost was changed to 20, 20, 10, and 5% for compost applied after 1992. The 40, 20, 10, and 5% N availability assumption was used for manure in all years. The residual values of N from previous manure and compost applications were considered when these materials were applied

Table 2. Composted and noncomposted beef cattle feedlot manure dry weight and N and P applications for 4 yr.

Treatment	1992	1993	1994	1995	Total
			dry Mg ha^{-1}		
Manure	46.9	18.5	12.1	14.5	92.0
Compost	34.6	49.5	25.1	36.4	145.6
			kg N ha^{-1}		
Manure	378	189	189	189	945
Compost	378	378	189	283	1228
			kg P ha^{-1}		
Manure	107	92	40	46	285
Compost	144	156	102	111	513

Table 3. Analysis of variance for the effects of tillage and treatment on N mineralization at five times during the growing season for 3 yr.

Variable	Time† 1	2	3	4	5
			$P > F$		
			1994		
Tillage	0.11	0.13	0.14	0.10	0.07
Treatment	0.01	0.01	0.01	0.01	0.01
Till × treat	0.05	0.28	0.66	0.23	0.38
CV (%)	10.5	9.7	13.2	10.9	13.1
			1995		
Tillage	0.83	0.95	0.85	0.79	0.53
Treatment	0.10	0.15	0.01	0.24	0.01
Till × treat	0.35	0.98	0.02	0.33	0.89
CV (%)	9.5	15.0	9.7	24.0	21.7
			1996		
Tillage	0.09	0.02	0.02	0.15	0.27
Treatment	0.03	0.53	0.08	0.09	0.29
Till × treat	0.65	0.63	0.62	0.66	0.84
CV (%)	10.7	12.3	16.8	18.3	18.4

† The tube extraction days for Times 1, 2, 3, 4, and 5 were 34, 56, 85, 106, and 131 in 1994; 27, 49, 71, 97, and 112 in 1995; 21, 48 74, 102, and 127 in 1996, respectively, from the tube insertion time.

in the 2nd, 3rd, and 4th yr. Nitrogen availability from manure and compost after the 4th yr was assumed to be minimal.

Growing season rainfall (1 May–15 October) was 773, 558, 307, and 425 mm in 1993, 1994, 1995, and 1996, respectively. Rainfall from 1 June to 31 August for the above years was 595, 405, 107, and 215 mm, respectively. The plots were irrigated three times in 1995 for a total of 75 mm during July and August to avoid losing the experiment. Soil temperature was determined by placing thermometers (sensor at 75-mm depth) that measured minimum and maximum temperatures. Thermal units were determined by adding the average soil daily temperatures (°C) for each resin tube sampling period (Honeycutt, 1999). Soil water content was determined by collecting three subsamples (0–150 mm) from each plot at several times throughout the growing season each year.

For the in situ N mineralization determination, a special soil probe (Art's Manufacturing and Supply, American Falls, ID) that holds an aluminum tube 5 cm in diameter was pushed into the soil in the corn row to a depth of 15 cm in 1994, 1995, and 1996. Mineralization was not determined in 1993. After removing the probe from the soil, the aluminum tube containing the soil was removed and a nylon bag, containing cation (Na^+ form) and anion (Cl^- form) resins (Sybron Chemical Inc., Birmingham, NJ), was placed in the bottom of the tube where 1.5 cm of soil had been excavated. The resin bags were kept in a ziplock bag prior to installation to avoid drying. Tubes were placed in 3 replications of manure, compost, and untreated check plots in all 3 yr. Nitrogen mineralization was not determined on the chemical fertilizer plots as N in ammonium nitrate is assumed to be 100% plant available. The tubes were placed in the corn rows for all treatments in both tillage systems to prevent excavation during cultivation in the conventional tillage plots and to avoid wheel track compacted areas. The tubes were inserted on 15 June in 1994 and 1995, and on 13 June in 1996. The tubes were placed in the corn rows after emergence in both tillage systems in all yr to locate the rows and place the tubes between two plants. Non-stretchable, heavy-duty nylon fabric (mesh size of 0.13 mm) was placed in the bottom of each tube to prevent root penetration into the soil cores. Twenty-five tubes were placed in each plot and five tubes were randomly selected and removed at ≈4 week intervals (5 times) during the growing season.

Table 4. Amounts of N mineralized for the two tillage systems at five times during the growing season for 3 yr.

Variable	Time† 1	2	3	4	5
			kg ha^{-1}		
			1994		
No-till	32.2	43.2	59.2	66.8	68.0
Tillage‡	41.0	57.2	69.1	83.6	84.7
			1995		
No-till	46.8	54.1	73.8	64.7	62.9
Tillage‡	45.7	54.6	71.9	68.1	73.4
			1996		
No-till	39.4	43.3	53.9	58.2	66.2
Tillage‡	48.4	58.9	75.0	71.4	79.4

† The tube extraction days for Times 1, 2, 3, 4, and 5 were 34, 56, 85, 106, and 131 in 1994; 27, 49, 71, 97, and 112 in 1995; 21, 48, 74, 102, and 127 in 1996, respectively, from the insertion time.

‡ Tillage included autumn and spring disking and cultivation for weed control.

The resins from all treatments were shaken and extracted in 2 *M* KCl solution five times (15 min each in a serial extraction) to extract all NH_4–N and NO_3–N. Nitrate and NH_4–N concentrations in the soil and resins were determined colorimetrically using a Lachat (Zellweger Analytics, Milwaukee, WI) system. The amount of N mineralized in the soil at each sampling time was determined by subtracting the soil concentrations of NO_3–N and NH_4–N at the beginning of the study from the concentrations at each sampling time and multiplying the product by total soil dry weight in each tube. The N in the resin was added to the soil N. The amount of N from nonfertilized check plots provided an indication of the amount of native soil N that was mineralized.

Mineralization rate constants were determined for the soil that received manure, compost, and no treatment by the following equation based on Smith et al. (1980)

$$N = N_o (1 - \exp[-kt]) \quad [1]$$

where N is the net amount of N mineralized at time t (day after tube insertion), N_o is the potentially mineralizable soil N, and k is the rate constant. Mineralization rate constants were estimated by using nonlinear regression (SAS Institute, 1985). Analysis of variance was used to analyze the mineralization data as influenced by tillage systems and treatments using SAS (SAS Institute, 1985). A probability level ≤0.05 was considered significant.

RESULTS AND DISCUSSION

Averaged across treatments, there were no significant effects of tillage on N mineralization at any of the sampling times in all 3 yr except sampling Times 2 and 3 in 1996, when conventional tillage resulted in greater mineralized N (Tables 3 and 4). Similar N mineralization occurred in the two tillage systems even though manure and compost were surface-applied in the no-till. It appears that surface application of manure and compost can provide similar N to a crop as when these resources are incorporated with tillage. In a laboratory incubation study, soil that had received poultry litter in strip-tillage (conservation) had more mineralizable N (6.1%) than poultry litter amended soil in conventional tillage (4.2%) (Kingery et al., 1996).

There was no difference in the amount of N mineral-

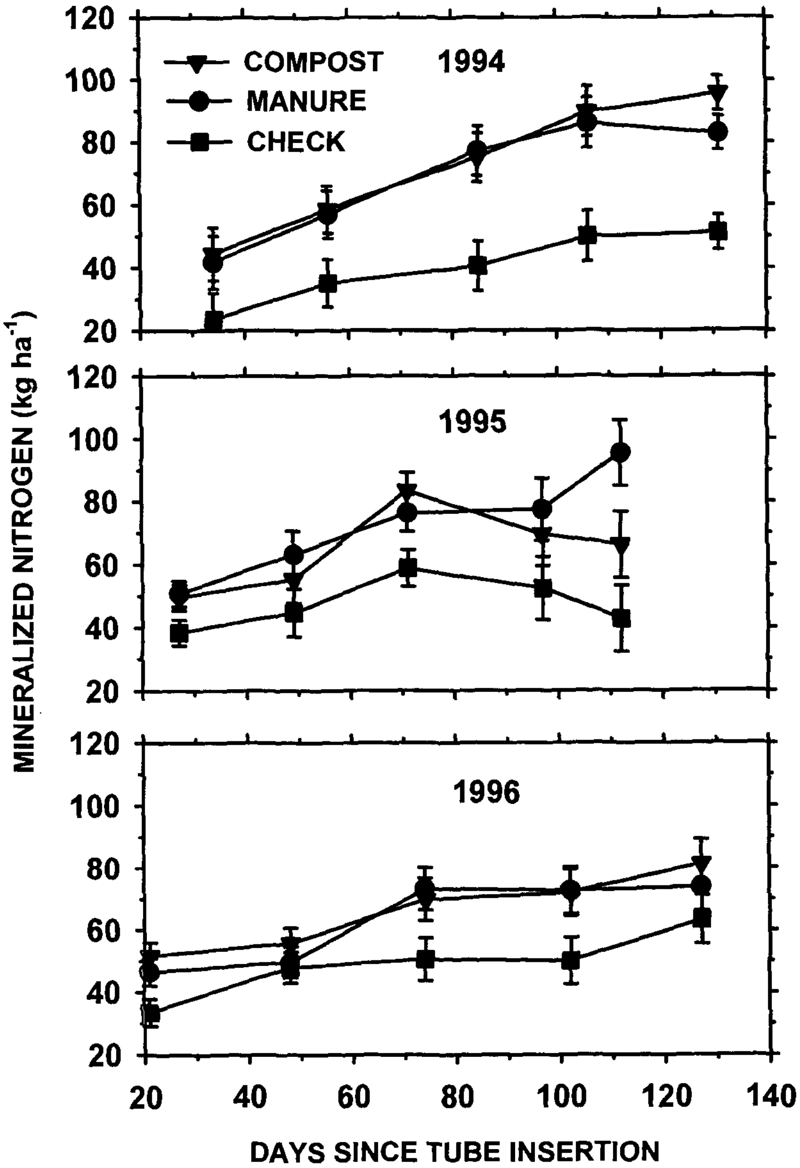

Fig. 1. Amounts of N mineralized from beef cattle feedlot manure or compost and check plots at five times during the growing season (mid-June to October) during 3 yr. The vertical bars are standard errors.

ized between manure and compost treatments at any of the sampling times except Time 5 in 1994 and 1995 (Fig. 1). Even though there was a trend for N mineralization to decrease after sampling Time 4 for manure in 1994, and for compost and untreated check after time 3 in 1995, these differences were not significant (Fig. 1). The unusual increase in mineralized manure N from Time 4 to Time 5 in 1995 could not be explained. Nitrogen extracted from the resins increased with time in all 3 yr (Table 5). More N was transported from the soil to the resin with time.

Nitrogen availability was determined by deducting the amount of N mineralized in the untreated check plots from those of the manure and compost treatments and dividing the difference by the total amount of N applied the previous autumn. About 19% of the applied total manure N and 12% of compost N were mineralized in 1994 (Table 6). These fractions were 28 and 12% in

Table 5. The amounts of N mineralized and remaining in the soil or moved to the resin at five times for 3 yr.

	Time†					
Variable	1	2	3	4	5	$LSD_{0.05}$
	kg ha^{-1}					
				1994		
Soil N	11	22	24	14	9	6
Resin N	26	28	40	61	67	11
				1995		
Soil N	43	46	50	31	33	12
Resin N	3	9	23	36	36	9
				1996		
Soil N	−2	5	11	3	8	5
Resin N	46	46	53	62	65	9

† The tube extractions days for Times 1, 2, 3, 4, and 5 were 34, 56, 85, 106, and 131 in 1994; 27, 49, 71, 97, and 112 in 1995; 21, 48, 74, 102, and 127 in 1996, respectively, from the insertion time.

Table 6. Nitrogen mineralized as a percentage of total and organic N applied from beef cattle feedlot manure or compost in the no-till and conventional systems at five times during the growing season for 3 yr.

	Time†									
	Total N					Organic N				
Variable	1	2	3	4	5	1	2	3	4	5
	%									
	1994									
Manure	9.6	11.5	19.4	19.1	16.8	10.1	12.1	20.5	20.2	17.7
Compost	5.5	6.2	9.1	10.5	11.8	5.5	6.2	9.1	10.5	11.8
	1995									
Manure	6.5	9.7	9.3	13.3	27.8	6.7	10.0	9.6	13.7	28.6
Compost	5.9	5.6	10.3	9.0	12.4	6.2	5.8	10.8	9.5	13.0
	1996									
Manure	6.9	1.0	12.0	11.9	5.6	7.5	1.1	13.0	12.9	6.1
Compost	6.4	2.8	6.8	7.7	6.4	6.7	2.9	7.1	8.1	6.7

† The tube extraction days for Times 1, 2, 3, 4, and 5 were 34, 56, 85, 106, and 131 in 1994; 27, 49, 71, 97, and 112 in 1995; 21, 48, 74, 102, and 127 in 1996, respectively, from the insertion time.

1995 and 12 and 8% in 1996, respectively (Table 6). The variability in time, based on standard errors, was greater in 1995 than other years. The mineralized organic N fractions were slightly higher than those from total manure and compost N (Table 6). About 5% of the total manure N and 4% of total compost N were in inorganic forms (NO_3 and NH_4). Inorganic N is plant available immediately after application. The mineralized N could have included some of the residual N from manure and compost applications in the previous years. The contribution of residual N was minimal since the potentially mineralizable N from manure and compost decreased with year (Table 7). Low N mineralization from compost can be attributed to the fact that most of the easily convertible N is lost during the composting process and the remaining N is in a more stable form (Eghball et al., 1997).

Based on plant N uptake, apparent N availability was 39% from total manure N and 22% from total compost N in the first year after application (1993) in this study (Eghball and Power, 1999a). Residual N availability from manure and compost applied for the 1993 growing season (assuming 39% N availability for manure and 22% for compost for the amounts added for the 1994 growing season) was only about 4% for manure and 3% for compost in 1994. In another study, Eghball and Power (1999b) found 18% second-year N availability from beef cattle manure and 8% for composted beef cattle feedlot manure when manure or compost were applied to provide for N requirements of corn for 2 yr (biennial application). In these calculations it was assumed that the N-uptake efficiency of available N was similar for inorganic fertilizer, manure, and compost. The N mineralization values determined in this study represented the amount of manure and compost organic N that became plant available during the growing season. Total plant available N includes manure and compost inorganic N, N mineralized following application in the autumn and early spring, and N mineralized during the growing season. It appears that the N mineralized during the growing season accounted for more than half of the total plant available N based on the plant N uptake method.

Table 7. Nitrogen mineralization constants for a soil receiving composted and noncomposted beef cattle feedlot manure and no treatment for 3 yr.

Year and Source	N_o†	k†
	kg ha^{-1}	d^{-1}
1994		
Check	60.2 ± 11.5	0.0148 ± 0.0059
Compost	117.5 ± 25.3	0.0128 ± 0.0053
Manure	98.0 ± 11.1	0.0167 ± 0.0043
1995		
Check	50.8 ± 3.5	0.0544 ± 0.0199
Compost	72.6 ± 5.6	0.0416 ± 0.0133
Manure	92.8 ± 12.3	0.0254 ± 0.0094
1996		
Check	56.4 ± 5.5	0.0395 ± 0.0154
Compost	74.3 ± 3.9	0.0437 ± 0.0097
Manure	73.8 ± 5.6	0.0364 ± 0.0105

† N_o is potentially mineralizable N, and k is the rate constant. The values following ± are standard errors of estimates.

The resins were effective in collecting the mineralized NH_4 and NO_3. Our unpublished data indicated that an amount equivalent to 275 N kg ha^{-1} was retained by the resins under field conditions during the growing season. Kjønaas (1999) found good correlation ($r^2 >$ 0.86) between throughfall solution containing inorganic N and NH_4, and NO_3 retained by resins.

It should be pointed out that manure or compost distribution was not a problem in this study since manure and compost were applied by hand uniformly on the plot area. In cases where distribution of manure and compost is not uniform, manure or compost samples may be applied directly to the surface or incorporated into the soil in the tube.

Mineralization rate constants for the manure and compost treatments are given in Table 7. The N_o values for manure and compost were greater in 1994 than in the other years. The N_o values for manure and compost in all three years were lower than the expected 151 N kg ha^{-1}, indicating less first yr and residual N mineralization from these resources than was assumed. The k values were smaller in 1994 than in the other years (Table 7), indicating increasing N mineralization with time in 1994. This may be because of greater average soil water content during the growing season in 1994

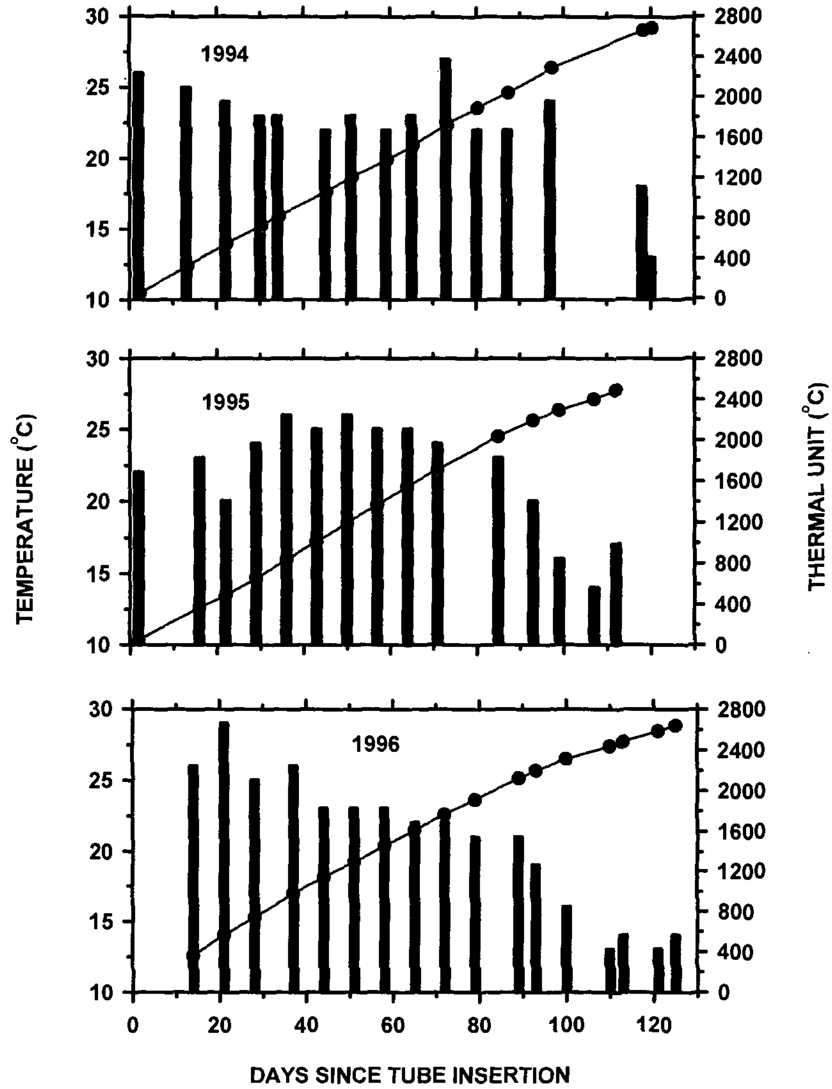

Fig. 2. Surface (0–75 mm) soil average temperature (bars) and thermal unit (lines and circles) during the growing season (mid-June to October) during 3 yr.

(268 kg m^{-3}) than other years (242 kg m^{-3} in 1995, and 229 kg m^{-3} in 1996).

Thermal units for the 3 yr are given in Fig. 2. Thermal units followed the same pattern in all 3 yr (Fig. 2). There were significant differences between tillage treatments for average soil water content from initiation to tube removal times in 1994 and 1995 ($P < 0.01$) but not in 1996 ($P > 0.82$). The average volumetric soil water contents for the no-till were 277, 255, and 228 kg m^{-3} during the study period in 1994, 1995, and 1996, respectively. These values were 258, 230, and 230 kg m^{-3} for the conventional system, respectively. Corn grain yield was less for no-till than tilled treatment in 1996, but was similar between the tillage systems in other years (Eghball and Power, 1999a). Lower yield for no-till than conventional tillage in 1996 may reflect lower available water for no-till compared with other years. No significant effect of treatment or tillage by treatment interaction was observed for average soil water content in all tube removal times in three years (data not shown). In a regression analysis across year, time, and treatment, N mineralization was significantly ($P = 0.0001$) related to the thermal unit ($N = 33.80 + 0.01579\,TU$; $R^2 = 0.21$, $n = 216$). Nitrogen mineralization was not significantly related ($P = 0.13$) to the soil water content in this study.

SUMMARY

The percentage of N mineralized during the June to October growing season following autumn application of composted beef cattle feedlot manure was about half that of noncomposted feedlot manure. Lower N availability from compost reflects the loss of easily convertible N compounds during composting and presence of stable N compounds. Nitrogen mineralization was similar in the no-till and conventional systems even though manure and compost were surface-applied in the no-till plots. This may be because feedlot manure is usually left on the feedlot surface for several months before it is collected, and about 50% of the excreted N is lost during this period. The remaining N is in a more stable form. Composting would further stabilize this N so that N loss from surface application is even less for compost. Nitrogen mineralization during the first growing season after application was about 21% of organic N in manure and 11% of organic N in compost. Measurements regarding inorganic N contents and N mineralization during autumn, winter (if any), and early spring would be needed to provide information regarding total plant N availability from applied manure and compost. The use of resins would not be possible during these cold periods in the northern Great Plains because freezing destroys the resins. Mineralization rate constants indicated that less N was mineralized from the residual manure or compost N than expected.

Thermal units were related to N mineralization indicating potential use of thermal unit or growing degree days to predict N mineralization from applied organic materials. Even though it is impossible to foresee the weather conditions in the growing season following autumn application of manure or compost, an average year may be used for modeling purposes. Cation and anion resins were effective in collecting NO_3–N and NH_4–N that would have been leached from the tubes. In cases where manure or compost distribution is not uniform during application, manure or compost may be placed directly on the soil inside the tube for mineralization measurements. Nitrogen mineralization needs to be considered when applying manure or compost for crop production to effectively utilize these resources and protect the environment.

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